A numerical study on the impact of ocean general circulation on aquaplanet climate with a coupled atmosphere-ocean-sea ice model

*Yuta Kawai[1,2], Yoshiyuki O. Takahashi[1,6], Masaki Ishiwatari[5], Seiya Nishizawa[2], Shin-ichi Takehiro[4], Kensuke Nakajima[3], Hirofumi Tomita[2], Yoshi-Yuki Hayashi[1,6]

1. Kobe Univ., 2. RIKEN AICS., 3. Kyusyu Univ., 4. Kyoto Univ., 5. Hokkaido Univ., 6. CPS

1. Introduction
The discovery of many exoplanets attracts the attention of planetary atmospheric scientists because the diversity of climates is expected on exoplanets. In order to understand the role of atmospheric circulation on determining the planetary climates, our research group also has explored the climates on a planet globally covered with water (aquaplanet) with an atmospheric general circulation model (AGCM) (Ishiwatari et al., 1998; Ishiwatari et al., 2007; hereinafter, referred as INTH98 and INTH07, respectively). In their study, ocean general circulation was not considered. However, ocean heat transport also may have a significant impact on the climate. The recent development of computational science enables a long time integration to be carried out with coupled atmosphere-ocean-sea ice models, and some studies of aquaplanet climates with considering ocean general circulation explicitly has been performed (e.g., Marshall et al., 2007; Rose et al., 2015). By their pioneering works, the dependence of climates of coupled aquaplanet system on some fundamental parameters, such as solar constant or planetary rotation period, has been obtained. However, in order to accumulate knowledge about the diversity of exoplanet climates, further parameter studies are needed (e.g., the dependence of aquaplanet climate on solar constant in the case of oceanic salinity much different from one on present earth) in addition to revisit the probability of previous results. So, we have developed our own ocean model, and coupled model.

In this study, using our coupled model, we perform solar constant dependence experiments in INTH07 with considering ocean general circulation, and the impact on determining aquaplanet climates are focused. In this presentation, we show some simulation results for present earth solar constant.

2. Numerical Model
The atmosphere model is an AGCM, DCPAM (https://www.gfd-dennou.org/library/dcpam/), in which 3-dimensional primitive equations and a transport equation for water vapor are solved. To reproduce INTH98 result, a gray atmosphere radiation scheme (Nakajima et al., 1992) and moist convective adjustment (Manabe et al., 1965) are used. The ocean model is a zonally averaged 2-dimensional ocean general circulation model in which hydrostatic Boussinesq equations are solved. The effect of meso-scale eddies and convection are parameterized (Gent and McWilliams, 1990; Marotzke, 1991). The model calculates the velocity, temperature and salinity. The sea ice model is a thermodynamics model based on Winton (2000), and calculates the thickness and temperature. The atmosphere, ocean and sea ice models are coupled with a coupler library (Arakawa et al., 2011).

3. Results
First, we have a numerical experiment in which surface albedo is fixed to zero everywhere same as experiments by INTH98. After the integration for several ten thousands of years, we obtain a statically equilibrium state with ice-line latitude of about 50°. The global circulation patterns are similar to that in Marshall et al. (2007), while the strength of circulations is quite smaller. In order to evaluate the effect of ocean circulation, we conduct further two experiments in which dynamical ocean is replaced by swamp or

slab ocean. According to the comparison of three experiments, ocean general circulation decreases the temperature difference between middle and low latitudes by about 5 K, and reduces the sea surface temperature (SST) at equator by about 4 K. However, the ice-line latitude and global mean SST in all cases are almost same. We also investigate the impact of ocean general circulation on the climate including ice-albedo feedback as INTH07. The result shows that, due to ocean large thermal inertia and motion, ice-line latitude retreats by about 10° and correspondingly global mean SST increases by about 5 K. As suggested in Rose et al. (2015), this indicates ocean inertia and heat transport have more significant impact on the climates in including ice-albedo feedback. In order to obtain a deeper understanding of ocean role on determining aquaplanet climates, we will perform solar constant dependence experiments.

Keywords: coupled atmosphere-ocean-sea ice model, aquaplanet climate, atmosphere and ocean heat transport, ice-albedo feedback